

APPLICATION
FOR
UNITED STATES LETTERS PATENT

TITLE: INFORMATION RETRIEVAL

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Express Mail Label No. EL 983020685 US

February 2, 2004
Date of Deposit

INFORMATION RETRIEVAL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation application of and claims priority to U.S. Application Serial No. 09/563,803, filed on May 2, 2000.

BACKGROUND

This invention relates to software that interfaces to information access platforms.

A search engine is a software program used for search and retrieval in database systems. The search engine often determines the searching capabilities available to a user. A web search engine is often an interactive tool to help people locate information available over the world wide web (WWW). Web search engines are actually databases that contain references to thousands of resources. There are many search engines available on the web, from companies such as Alta Vista, Yahoo, Northern Light and Lycos.

SUMMARY

In an aspect, the invention features a method of accessing information from a collection of data including receiving a query, generating an inverse index of the collection of data and generating results to the query in conjunction with the inverse index. Generating the inverse index includes storing a canonical non-terminal representation of the data in the inverse index. Generating the inverse further includes storing hierarchical information generated from the collection of data, and applying a parser and grammar

rules to the collection of data to produce a canonical non-terminal representation of the data.

Generating results includes applying the parser and the grammar rules to the query to produce a query canonical form and matching the query canonical form to the canonical non-terminal representation of the data in the inverse index.

Embodiments of the invention may have one or more of the following advantages.

An information retrieval process purpose is to take a collection of documents on a main server collection of data containing words, generate an inverse index known as an IR index, and use the IR index to produce answers to a user query. The process may then leverage grammar it develops for front end processing when building the IR index to generate phased synonyms (or phrased aliases) for the document. More specifically, the process may apply the parser and grammar rules to the document before the IR index is built.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features and other aspects of the invention will be described further in detail by the accompanying drawings, in which:

FIG. 1 is a block diagram of a network configuration.

FIG. 1A is a flow diagram of a search process.

FIG. 2 is a flow diagram of an information access process.

FIG. 3 is a flow diagram of a meaning resolution process used by the information access process of FIG. 2.

FIG. 4 is a block diagram of an information interface.

FIG. 5 is a flow diagram of a reduction and summarization process used by the information access process of FIG. 2.

FIG. 6 is a flow diagram of a prose process used by the information access process of FIG. 2.

FIG. 7 is flow diagram of a bootstrap process used by the information access process of FIG. 2.

FIG. 8 is flow diagram of a database aliasing process used by the information access process of FIG. 2.

FIG. 9 is flow diagram of a database aliasing file generation process used by the information access process of FIG. 2.

FIG. 10 is a flow diagram of a query expansion process used by the information access process of FIG. 2.

DETAILED DESCRITPION

Referring to FIG. 1, a network configuration 2 for executing an information access process includes a user computer 4 connected via a link 6 to an Internet 8. The link 6 may be a telephone line or some other connection to the Internet 8, such as a high speed T1 line. The network configuration 2 further includes a link 10 from the Internet 8 to a client system 12. The client system 12 is a computer system having at least a central processing unit (CPU) 14, a memory (MEM) 16, and a link 18 connected to a storage device 20. The storage device 20 includes a database 21, which contains information that a user may query. The client system 12 is also shown to include a link 22 connecting the client system 12 to a server 24. The server 24 includes at least a CPU 25 and a memory 26. A plug-in 27 is shown resident in the memory 26 of the server 24. The plug-in 27 is an application program module that allows a web site code running on the client system 12 to execute an information access process residing in the memory 26 of the server 24. The plug-in 27 allows the web site application to incorporate results

returned from the information access process while it is generating HTML for display to the user's browser (not shown). HTML refers to Hypertext Markup Language and is the set of "markup" symbols or codes inserted in a file intended for display on a World Wide Web browser. The markup tells the Web browser how to display a Web page's words and images for the user. The individual markup codes are referred to as elements (also referred to as tags). As is shown, the server 24 shares access to the database 21 on the storage device 20 via a link 28. Other network configurations are possible. For example, a particular network configuration includes the server 24 maintaining a local copy of the database 21. Another network configuration includes the Internet 8 connecting the client system 12 to the server 24.

Referring to FIG. 1A, a search process 30 residing on a computer system includes a user using a web-browser on a computer connecting 32 to the Internet and accessing a client system. Other embodiments include a direct connection from the user computer to the client system. The client system displays 33 a page on the web browser of the user and the user inputs 34 a query in a query input box of the displayed page. The query is sent 35 to an information access process residing on a server for processing. The information access process processes 36 the query and sends the results to the client system. The results are then displayed 37 to the user.

Referring to FIG. 2, an information access process 40 on a computer system receives 42 a query by a user. The query may be a word or multiple words, sentence fragments, a complete sentence, and may contain punctuation. The query is normalized 44 as pretext. Normalization includes checking the text for spelling and proper separation. A language lexicon is also consulted during normalization. The language lexicon

specifies a large list of words along with their normalized forms. The normalized forms typically include word stems only, that is, the suffixes are removed from the words. For example, the word "computers" would have the normalized form "computer" with the plural suffix removed.

The normalized text is parsed 46, converting the normalized text into fragments adapted for further processing. Annotating words as punitive keys and values, according to a feature lexicon, produces fragments. The feature lexicon is a vocabulary, or book containing an alphabetical arrangement of the words in a language or of a considerable number of them, with the definition of each; a dictionary. For example, the feature lexicon may specify that the term "Compaq" is a potential value and that "CPU speed" is a potential key. Multiple annotations are possible.

The fragments are inflated 48 by the context in which the text inputted by the user arrived, e.g., a previous query, if any, that was inputted and/or a content of a web page in which the user text was entered. The inflation is preformed by selectively merging 50 state information provided by a session service with a meaning representation for the current query. The selective merging is configurable based on rules that specify which pieces of state information from the session service should be merged into the current meaning representation and which pieces should be overridden or masked by the current meaning representation.

The session service stores all of the "conversations" that occur at any given moment during all of the user's session. State information is stored in the session service providing a method of balancing load with additional computer configurations. Load balancing may send each user query to a different configuration of the computer system. However,

since query processing requires state information, storage of station information on the computer system will not be compatible with load balancing. Hence, use of the session service provides easy expansion by the addition of computer systems, with load sharing among the systems to support more users.

The state information includes user specified constraints that were used in a previous query, along with a list of features displayed by the process 40 and the web page presented by the main server. The state information may optionally include a result set, either in its entirety or in condensed form, from the previous query to speed up subsequent processing in context. The session service may reside in one computer system, or include multiple computer systems. When multiple computer systems are employed, the state information may be assigned to a single computer system or replicated across more than one computer system.

Referring now to FIG. 3, the inflated sentence fragments are converted 52 into meaning representation by making multiple passes through a meaning resolution process 70. The meaning resolution process 70 determines 72 if there is a valid interpretation within the text query of a key-value grouping of the fragment. If there is a valid interpretation, the key value grouping is used 74. For example, if the input text, i.e., inflated sentence fragment, contains the string "500 MHz CPU speed," which may be parsed into two fragments, "500 MHz" value and "CPU speed" key, then there is a valid grouping of key = "CPU speed" and value = "500 MHz".

If no valid interpretation exists, a determination 76 is made on whether the main database contains a valid interpretation. If there is a valid interpretation in the main database, the key value group is used 74. If no valid

interpretation is found in the main database, the process 70 determines 78 whether previous index fields have a high confidence of uniquely containing the fragment. If so, the key value grouping is used 74. If not, other information sources are searched 80 and a valid key value group generated 82. If a high confidence and valid punitive key is determined through one of the information sources consulted, then the grouping of the key and value form an atomic element are used 74. To make it possible to override false interpretations, a configuration of grammar can also specify manual groupings of keys and values that take precedence over the meaning resolution process 70.

Referring again to FIG.2, meaning resolved fragments, representing the user query, are answered 54. In providing an answer or answers, logic may decide whether or not to go out to the main database, whether or not to do a simple key word search, or whether or not to do direct navigation, and so forth. Answer or answers are summarized and organized 56. Summarization and organization may involve intelligent discarding of excessive and unneeded details to provide more meaningful results in response to the user query.

When a user asks a question, i.e., submits a query, there is usually no way to predict how many appropriate results will be found. The process 40 attempts to present the user with no more information than can be reasonably absorbed. This is often dictated by the amount of space available on the users displayed web page.

Prose is generated 58. The prose represents the specific query the user initially asked, followed by organized and summarized results to the user query. The prose and organized answers are outputted 60 to the user for display. Output to the user may involve producing HTML of the prose and organized

answers and/or XML for transmission of the organized answers and dynamic prose back to the main server for HTML rendering. XML refers to extensive markup language, a flexible way to provide common information formats and share both the format and the data on the word wide web, intranets, and elsewhere. Any individual or group of individuals or companies that wants to share information in a consistent way can use XML.

Referring to FIG. 4, the control logic of process 40 includes an information interface 80. The purpose of the information interface 80 is to isolate the control logic from the details of any given web site on the main server or other servers, e.g., how they store particular information. For example, different web sites will name things differently and/or store things differently. The information interface 80 provides a standard format for both receiving information from, and sending information to, the control logic of process 40, and normalizes the interface to various information sources. The information interface 80 includes an information retrieval process 82, a database (db) aliasing process 84, a URL driver process 86 and a storage process 88.

An exemplary illustration of a standard format used by the information interface 80 is shown as follows:

```
{_
  :features {features
    :_ {feature
      :key 'product price'}
    :_ {feature
      :key 'product min age'}
    :_ {feature
      :key 'product max age'}
    :_ {feature
      :key 'product name'}
    :_ {feature
      :key 'sku'}}
  :constraints {or
    :_ {and
      :_ {feature
        :key 'product description'
        :value {or
          :_ {value
```

```

                                     :eq
'fire trucks'                                     :kwid
'fire trucks' }}}}}
:sort {features
      :_ {feature
          :key 'product price'}
      :_ {feature
          :key 'product min age'}
      :_ {feature
          :key 'product max age'}
      :_ {feature
          :key 'product name'}
      :_ {feature
          :key 'sku' }}}

```

The information interface 80 handles and formats both "hard" and "soft" searches. A hard search typically involves a very specific query for information, while a soft search typically involves a very general query for information. For example, a hard search may be for the price to be less than \$500 where price is a known column in the database and contains numeric values. The IR engine to include occurrences of "fire truck" within textual descriptions may interpret a soft search for "fire engine".

The URL driver process 86 maintains a URL configuration file. The URL configuration file stores every detail of a web site in compressed format. The compression collapses a set of web pages with the same basic template into one entry in the URL configuration file. By way of example, the following is a sample portion of a URL configuration file entry:

```

/newcar/$Manufacturer/$Year/$Model/
  keys: overview

/newcar/$Manufacturer/$Year/$Model/safetyandreliability.
asp
  keys: safety reliability

```

The db aliasing process 84 handles multiple words that refer to the same information. For example, the db aliasing process 84 will equate "laptop" and "notebook" computers and "pc" and "personal computer."

The URL driver process 86 includes bi-directional search logic for interacting with the URL configuration file. In a "forward" search direction, a specific query is received and the search logic searches the URL configuration file for a best match or matches and assigns a score to the match or matches, the score representing a relative degree of success in the match. The score is determined by the number of keys in the URL configuration entry that match the keys desired by the current meaning representation of the query. More matching keys will result in a higher score.

In a "reverse" direction, the search logic contained within the URL driver process 86 responds to a query by looking at the contents of the web page in which the user is currently viewing and finds the answer to the new user query in combination with the features of the web page which the user is viewing, along with a score of the match or matches. Thus, the search logic of the URL driver process 86 looks at the current web page and connects current web page content with current user queries, thus deriving contacts from the previous line of questioning.

As described with reference to FIG. 2, the information access process 40 contains control logic to provide answers to a user's query. The answers are summarized and organized. Typically, the results of a specific database search, i.e., user query, will identify many rows of results. These rows will often result in more than one web page of displayed results if the total result is taken into account. The information access process 40 reduces the number of rows of answers in an iterative fashion.

Referring to FIG. 5, a reduction and summarization process 110 determines 112 a count of the total number of results obtained from searching the main database. The

reduction and summarization process 110 determines 114 the amount of available space on the web page for display of the answers. A determination 116 is made as to whether the number of results exceeds the available space on the web page. If the number of results does not exceed the available space on the web page the results are displayed 118 on the web page. If the number of results exceeds available space on the web page, a row of results is eliminated 120 to produce a subset of the overall results. The number of results contained within the subset is determined 122. The determination 116 of whether the number of results contained within the subset exceeds available space on the web page is executed. The reduction and summarization process 110 continues until the number of results does not exceed available display space on the web page.

When a reduction of results is made, the reduction and summarization process 110 has no prior knowledge of how it will affect the total count, i.e., how many rows of data will be eliminated. Reductions may reduce the overall result count, i.e., rows of result data, in different ways. Before any reduction and summarization is displayed in tabular form to the user, the resultant data is placed in a hierarchical tree structure based on its taxonomy. Some searches will generate balanced trees, while others will generate unbalanced trees. Further, some trees will need to be combined with other trees. To reduce the resultant data, the reduction and summarization process 110 looks at the lowest members of the tree, i.e., the leaves, and first eliminates this resultant data. This results in eliminating one or more rows of data and the overall count of resultant data. If the overall count is still too large, the reduction and summarization process 110 repeats itself and eliminates another set of leaves.

Eliminating rows (i.e., leaves) to generate a reduced result set of answers allows the reduction and summarization process 110 to reduce identical information but maintain characterization under identical information in the hierarchical tree structure. The identical rows representing identical information can be collapsed. For example, if the eliminated row in the reduced result set contains specific price information, collapsing the eliminated row may generate price ranges instead of individual prices.

As mentioned previously, some results may generate multiple trees. In a particular embodiment, to reduce the overall amount of resultant data in the result set, information is eliminated where the greatest number of leaves is present across multiple trees.

Referring again to FIG. 2, it should be noted that sometimes the information access process 40 will provide no summarization and/or reduction of results, e.g., the user asks for no summarization or the results are very small.

Organization of resultant data generally puts the answers to the user's query into a hierarchy, like a table, for example, and the table may include links to other web pages for display to the user. Links, i.e., addresses associated with each row of the displayed results, are encoded within each element of the hierarchical tree structure so that the user may navigate to a specific web page by clicking on any of the links of the resultant rows of displayed data. The encoding is done by including a reference to a specific session known by the session service along with the address to an element in the table of results displayed during the specific session. State information provided by the session service can uniquely regenerate the table of results. The

address is a specification of the headings in the table of results.

For example, if an element in the hierarchical structure is under a subheading "3" which is under a major heading "E," the address would specify that the major heading is "E" and that the subheading is "3." Response planning may also include navigation to a web page in which the user will find a suitable answer to their query.

As previously described, prose is generated and added to the results.

Referring to FIG. 6, a prose process 140 includes receiving 142 the normalized text query. The normalized text query is converted 144 to prose and the prose displayed 146 to the user in conjunction with the results of the user query.

The prose process 140 receives the normalized text query as a text frame. The text frame is a recursive data structure containing one or more rows of information, each having a key that identifies the information. When the text frame is passed to the prose process 140 it is processed in conjunction with a prose configuration file. The prose configuration file contains a set of rules that are applied recursively to the text frame. These rules include grammar having variables contained within. The values of the variables come from the text frame, so when combined with the grammar, prose is generated. For example, one rule may be "there are \$n products with \$product." The variables \$n and \$product are assigned values from an analysis of the text frame. The text frame may indicate \$n = 30 and \$product = leather. Thus, the prose that results in being displayed to the user is "there are 30 products with leather."

More than one rule in the prose configuration file may match the text frame. In such a case, prose process 140 will

recursively build an appropriate prose output. In addition, if two rules in the prose configuration file match identically, the prose process 140 may arbitrarily select one of the two rules, but the database can be weighted to favor one rule over another. In some cases, default rules may apply. In addition, some applications may skip over keys and may use rules more than once.

The prose configuration file also contains standard functions, such as a function to capitalize all the letters in a title. Other functions contained within the prose configuration may pass arguments.

The information access process 40 (of FIG. 2) interfaces with a number of configuration files in addition to the prose configuration file. These configuration files aid the information access process 40 in processing queries with the most current data contained in the main server database. For example, the information access process 40 has a bootstrapping ability to manage changes to a web page of the main server and to the main server database. This bootstrapping ability is needed so that when the main server database changes occur, the information access process 40 utilizes the most current files.

The information access process 40 also includes a number of tools that analyze the main server database and build initial versions of all of the configuration files, like the prose configuration file; this is generally referred to as bootstrapping, as described above. Bootstrapping gives the information access process 40 "genuine" knowledge of how grammar rules for items searching looks like, specific to the main server database being analyzed.

Referring to FIG. 7, a bootstrap process 170 extracts 172 all text corresponding to keys and values from the main server

database. The extracted text is placed 174 into a feature lexicon. A language lexicon is updated 176 using a general stemming process. Grammar files are augmented 178 from the extracted keys and values. Generic grammar files and previously built application-specific grammar files are consulted 180 for rule patterns, that are expanded 182 with the newly extracted keys and values to comprise a full set of automatically generated grammar files.

For example, if an application-specific grammar file specifies that "Macintosh" and "Mac" parse to the same value, any extracted values containing "Macintosh" or "Mac" will be automatically convert into a rule containing both "Macintosh" and "Mac." The structuring of the set of grammar files into generic, application-specific and site-specific files allows for maximum automatic generation of new grammar files from the main server database. The bootstrapping process 170 can build the logic and prose configuration files provided that a system developer has inputted information about the hierarchy of products covered in the main server database.

The hierarchy for a books database, for example, may include a top-level division into "fiction" and "nonfiction." Within fiction, the various literary genres might form the next level or subdivision, and so forth. With knowledge of this hierarchy, the bootstrapping process 170 configures the logic files through link linguistic concepts relating to entries in the hierarchy with products in the main server database, so that the logic is configured to recognize, for example, that "fiction" refers to all fiction books in the books database. The logic configuration files are also automatically configured by default, and summarization and organization of the results uses all levels of the hierarchy. The prose configuration files are automatically generated with

rules specifying that an output including, for example, mystery novels, should include the category term "mystery novels" from the hierarchy. The bootstrapping process 170 may also "spider" 184 a main server database so as to build a language lexicon of the site, e.g., words of interest at the site. This helps building robust configuration files. Spidering refers to the process of having a program automatically download one or more web pages, further downloading additional pages referenced in the first set of pages, and repeating this cycle until no further pages are referenced or until the control specification dictates that the further pages should now be downloaded. Once downloaded, further processing is typically performed on the pages. Specifically, the further processing here involves extracting terms appearing on the page to build a lexicon.

When the bootstrapping process 170 executes after original configuration files have been generated, the original configuration files are compared with the current configuration files and changes added incrementally as updates to the original configuration files.

Referring again to FIG. 3, the information interface 80 includes the database aliasing process 88. The database aliasing process 88 provides a method to infer results when no direct match occurs. Referring to FIG. 8, a database (db) aliasing process 200 includes generating 202 and aliasing the file, and applying 204 the aliasing file to a user query. The automatic generation of the database aliasing file reduces the amount of initial development effort as well as the amount of ongoing maintenance when the main server database content changes.

Referring to FIG. 9, a database aliasing file generating process 220 includes extracting 222 names from the main server

database. The extracted names are normalized 224. The normalized names are parsed 226. The language lexicon is applied 228 to the normalized parsed names. A determination 230 is made on whether multiple normalized names map to any single concept. If so, alias entries are stored 232 in the database aliasing file. In this manner, the grammar for the parser can be leveraged to produce the database aliasing file. This reduces the need for the system developer to input synonym information in multiple configuration files and also allows imprecise aliases, which are properly understood by the parser, to be discovered without any direct manual entry.

The db aliasing file, like many of the configuration files, is generated automatically, as described with reference to FIG. 9. It can also be manually updated when the context of the database under investigation changes. The database aliasing file is loaded and applied in such a way as to shield its operations from the information interface 80 of FIG. 3.

In a particular embodiment, the application of the db aliasing file to a query can be used in two directions. More specifically, in a forward direction, when a user query is received, applying the database aliasing file to the user query and resolving variations of spelling, capitalization, and abbreviations, normalized the user query, so that a normalize query can be used to search the main server database. In a reverse direction, if more than one alias is found, the search results will normalize on a single name for one item rather than all possible aliases found in the main server database file.

Referring again to FIG. 4, the information interface 80 includes the information retrieval (IR) process 82. The information retrieval process 82 purpose is to take a collection of documents on a main server database containing

words, generate an inverse index known as an IR index, and use the IR index to produce answers to a user query. The information access process 40 (of FIG. 2) leverages grammar it develops for front end processing when building the IR index to generate phrased synonyms (or phrased aliases) for the document. More specifically, the information access process 40 applies the parser and grammar rules to the document before the IR index is built. The effect of this can be described by way of example. One rule may indicate the entity "laptop" goes to "laptop" or "notebook." Thus, during parsing, if "notebook" is found, it will be replaced by the entity "laptop," which then gets rolled into the IR index.

At search time, the information access process 40 attempts to find documents containing the search terms of the user query, and in addition, the incoming user search terms are run through the parser, that will find multiple entities, if they exist, of the same term. Thus, combining the parser and the grammar rules, the information access process 40 maps a user query into its canonical form of referring to the item.

The information retrieval process 40 may also process a grammar and generate a grammar index, which can help find other phrased synonyms that other methods might not find. For example, "Xeon", an Intel Microprocessor whose full designation is the "Intel Pentium Xeon Processor," may be represented in canonical form as "Intel Xeon Processor." If a user query is received for "Intel," "Xeon" would not be found without the grammar index of the information access process 40. The information access process 40 will search the grammar index and produce a list of all grammar tokens containing "Intel," and add this list to the overall search so that the results would pick up "Xeon," among others.

The use of the parser and grammar rules to specify the expansion of a full user query to include synonyms allows for centralization of linguistic knowledge within the grammar rules, removing a need for additional manual configuration to gain the query expansion functionality.

Referring to FIG. 10, a query expansion process 250 includes normalizing 252 and parsing 254 the punitive text. The canonical non-terminal representations are inserted 256 into an IR index in place of the actual punitive text.

In an embodiment, the punitive text is used "as-is." However, when a user requests a search, the punitive search phrase is processed according to the grammar rules to obtain a canonical non-terminal representation. The grammar rules are then used in a generative manner to determine which other possible phrases could have generated the same canonical non-terminal representation. Those phrases are stored in the IR index.

The "as-is" method described above is generally slower and less complete in query expansion coverage, because it may take too long to generate all possible phrases that reduce to the same canonical non-terminal representation, so a truncation of the possible phrase list can occur. However, the "as-is" method has the advantage of not requiring re-indexing the original text whenever the grammar rules are updated.

In a particular embodiment, the information access process 40 (of FIG. 2) combines an IR index search with a main server database search to respond to queries that involve a combination of structured features stored in a database (e.g., price, color) and unstructured information existing in free text. Structured Query Language (SQL) is used to interface to a standard relational database management system (RDBMS). To

jointly search an RDBMS and an IR index, the information access process 40 issues an unstructured search request to the IR index, uses the results, and issues a SQL query that includes a restriction to those initial IR index search results. However, the free text information in the IR index may not always correspond to individual records in the RDBMS. In general, there may be many items in the IR index that correspond to categories of items in the RDBMS. In order to improve the efficiency of searches involving such items in the IR index, the IR index is further augmented with category hierarchy information. Thus, a match to an item in the IR index will also retrieve corresponding category hierarchy information, which can then be mapped to multiple items in the RDBMS.

The information access process 40 parser contains the capability of processing large and ambiguous grammar efficiently by using a graph rather than "pure" words. The parser allows the information access process 40 to take the grammar file and an incoming query and determine the query's structure. Generally, the parser pre-compiles the grammar into a binary format. The parser then accepts a query as input text, processes the query, and outputs a graph.

LR parsing is currently one of the most popular parsing techniques for context-free grammars. LR parsing is generally referred to as "bottom-up" because it tries to construct a parse tree for an input string beginning at the leaves (the bottom) and working towards the root (top). The LR parser scans the input string from left to right and constructs a right most derivation in reverse.

The information access process 40 improves on the LR parser by adding the ability to handle ambiguous grammars efficiently and by permitting the system developer to include

regular expressions on the right hand side of grammar rules. In the "standard" LR parser, an ambiguous grammar would produce a conflict during the generation of LR tables. An ambiguous grammar is one that can interpret the same sequence of words as two or more different parse trees. Regular expressions are commonly used to represent patterns of alternative and/or optional words. For example, a regular expression "(a|b)c+" means one or more occurrences of the letter "c" following either the letter "a" or the letter "b."

In traditional LR parsing, a state machine, typically represented as a set of states along with transitions between the states, is used together with a last-in first-out (LIFO) stack. The state machine is deterministic, that is, the top symbol on the stack combined with the current state specifies conclusively what the next state should be. Ambiguity is not supported in traditional LR parsing because of the deterministic nature of the state machine.

To support ambiguity the information access process 40 extends the LR parser to permit non-determinism in the state machine, that is, in any given state with any given top stack symbol, more than one successor state is permitted. This non-determinism is supported in the information access process 40 with the use of a priority queue structure representing multiple states under consideration by the parser. A priority queue is a data structure that maintains a list of items sorted by a numeric score and permits efficient additions to and deletions from the queue. Because the parser used in the information access process 40 is permitted to be simultaneously in multiple states, the parser tracks multiple stacks, one associated with each current state. This may lead to inefficiency. However, since the multiple concurrent states tend to have a natural "tree" structure, because typically one

state transitions to a new set of states through multiple putative transitions, the multiple stacks can be structured much more efficiently in memory usage via a similar tree organization.

In a traditional LR parser, the state diagram can be very large even for moderate size grammars because the size of the state diagram tends to grow exponentially with the size of the grammar. This results in tremendous memory usage because grammars suitable for natural language tend to be much larger than those for a machine programming language. In order to improve the efficiency of the state diagrams, the information access process 40 makes use of empty transitions that are known as "epsilon" transitions. The exponential increase in size occurs because multiple parses may lead to a common rule in the grammar, but in a deterministic state diagram, because the state representing the common rule needs to track which of numerous possible ancestors was used, there needs to be one state of each possible ancestor. However, because the information access process 40 has expanded the LR parser to support ambiguity via support for a non-deterministic state diagram, the multiple ancestors can be tracked via the previously described priority queue/stack tree mechanism. Thus, a common rule can be collapsed into a single state in the non-deterministic state diagram rather than replicated multiple times. In general, performing this compression in an optimal fashion is difficult. However, a large amount of compression can be achieved by inserting an epsilon whenever the right-hand side of a grammar rule recurses into a non-terminal. This has the effect of causing all occurrences of the same non-terminal in different right-hand-sides to be collapsed in the non-deterministic state diagram. A concern which the information access process 40 addresses is that any

"left-recursion," that is, a rule which eventually leads to itself either directly or after the application of other rules, will result in a set of states in the non-deterministic state diagram that can be traversed in a circular manner via epsilon transitions. This would result in a potential infinite processing while parsing. In order to prevent infinite processing, if there are multiple possible epsilon transitions in series, they are reduced to a single epsilon transition. This may result in a small amount of inaccuracy in the parser, but avoids the potential for infinite processing.

The parser of the information access process 40 has also been expanded to support regular expressions on the right-hand-side of context-free grammar rules. Regular expressions can always be expressed as context-free rules, but it is tedious for grammar developers to perform this manual expansion, increasing the effort required to author a grammar and the chance for human error. Implementation of this extension would be to compile the regular expressions into context-free rules mechanically and integrate these rules into the larger set of grammar rules. Converting regular expressions into finite state automata through generally known techniques, and then letting a new non-terminal represent each state in the automata can accomplish this. However, this approach results in great inefficiency during parsing because of the large number of newly created states. Also, this expansion results in parse trees which no longer correspond to the original, unexpanded, grammar, hence, increasing the amount of effort required by the grammar developer to identify and correct errors during development.

An alternative used by the information access process 40 is to follow the finite state automaton corresponding to a regular expression during the parsing as if it were part of

the overall non-deterministic state diagram. The difficulty that arises is that right-hand-sides of grammar rules may correspond to both regular expressions of terminal and non-terminal symbols in the same rule. Thus, when the LR parser of the information access process 40 reaches a reduce decision, there is no longer a good one-to-one correspondence between the stack symbols and the terminal symbols recently processed. A technique needs to be implemented in order to find the start of the right-hand side on the stack. However, because the parser uses epsilons to mark recursions to reduce the state diagram size, the epsilons also provide useful markers to indicate on the stack when non-terminals were pursued. With this information, the LR parser of the information access process 40 is able to match the stack symbols to the terminals in the input text being parsed.

Another efficiency of the LR parser of the information access process 40 involves the ability to support "hints" in the grammar. Because natural language grammars tend to have a large amount of ambiguity, and ambiguity tends to result in much lengthier parsing times. In order to keep the amount of parsing time manageable, steps must be taken to "prune" less promising putative parses. However, automatic scoring of parses for their "promise" is non-trivial. There exist probabilistic techniques, which require training data to learn probabilities typically associated with each grammar rule. The LR parser of the information access process 40 uses a technique that does not require any training data. A grammar developer is allowed to insert "hints," which are either markers in the grammar rules with associated "penalty costs" or "anchors." The penalty costs permit the grammar developer to instruct the LR parser of the information access process 40 to favor certain parses over others, allowing for pruning of

less-favored parses. Anchors indicate to the LR parser that all other putative parses that have not reached an anchor should be eliminated. Anchors thus permit the grammar developer to specify that a given phrase has a strong likelihood of being the correct parse (or interpretation), hence, all other parses are discarded.

Another concern with supporting ambiguous grammars is that the large number of parses consumes much memory to represent. The LR parser of the information access process 40 is modified to represent a list of alternative parse trees in a graph structure. In the graph representation, two or more parse trees that share common substructure within the parse tree are represented as a single structure within the graph. The edges in the graph representation correspond to grammar rules. A given path through the graph represents a sequential application of a series of grammar rules, hence, uniquely identifying a parse tree.

Once a graph representation of potential parses is generated, at the end of parsing a frame representation of the relevant potential parses is outputted. This is achieved via a two-step method. First, the graph is converted into a series of output directives. The output directives are specified within the grammar by the grammar developer. Second, frame generation occurs as instructed by the output directives. The first step is complicated by the support for regular expressions within the grammar rules because a node in the parse tree may correspond to the application of a regular expression consisting of non-terminals, which in turn corresponds to application of other grammar rules with associated output directives. The identity of these non-terminals is not explicitly stated in the parse tree. In order to discover these identities, during the first step, the

process follows a procedure very similar to the previously described LR parser, but instead, because one already has a parse tree, the parse tree is used to "guide" the search control strategy. Once the proper identities are discovered, the corresponding output directives are sent to the second stage.

The information interface 80 frequently needs to access multiple tables in an RDBMS in order to fulfill a data request made by the control logic of the information access process 40. It is unwieldy for the system developer to specify rules on which tables need to be accessed to retrieve the requested information. Instead, it is much simpler for the system developer to simply specify what information is available in which tables. Given this information, the information interface 80 finds the appropriate set of tables to access, and correlates information among the tables. The correlation is carried out by the information interface 80 (of FIG. 4) requesting a standard join operation in SQL.

In order to properly identify a set of tables and their respective join columns, the information interface 80 (of FIG. 4) views the set of tables as nodes in a graph and the potential join columns as edges in a graph. Given this view, a standard minimum spanning tree (MST) algorithm may be applied. However, the input to the information interface 80 is a request based on features and not on tables. In order to identify the tables and join columns, the information interface 80 treats the set of tables as nodes in a graph and the set of join columns as edges in the graph. A standard minimum spanning tree (MST) algorithm can be applied. One problem is that the same feature may be represented in more than one table. Thus, there may be multiple sets of tables that can potentially provide the information requested. In

order to identify the optimal set of tables and join columns, the information interface 80 must apply a MST algorithm to each possible set of tables. Because the number of possible sets can expand exponentially, this can be a very time consuming process. The information interface 80 also has the ability to make an approximation as follows. There is a subset, which may be zero, one, or more, of features, which are represented in only one table per feature. These tables therefore are a mandatory subset of the set of tables to be accessed. In the approximation, the information interface 80 first applies a MST algorithm to the mandatory subset, and then expands the core subset so as to include all the requested tables. The expansion seeks to minimize the number of additional joins needed to cover each feature not covered by the mandatory subset.

Other embodiments are within the following claims.